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RESIDUAL STRENGTH DEGRADATION FOR ADVANCED COMPOSITES

LOCKHEED-CALIFORNIA COMPANY • BURBANK
A DIVISION OF LOCKHEED CORPORATION

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RESIDUAL STRENGTH DEGRADATION FOR ADVANCED COMPOSITES

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Prepared by

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Prepared for

Air Force Flight Dynamics Laboratory
Air Force Systems Command
Aeronautical Systems Division
Wright-Patterson AFB, Ohio

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FOREWORD

The work reported herein was accomplished under Contract F33615-77-C-3084, Project 2401, Work Unit 24010117, sponsored by the Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433. Dr. G. P. Sendeckyj, AFFDL/FBE, is the Air Force Project Engineer.

The program is being conducted by the Structures and Materials Department of the Lockheed-California Company. The program is directed by the Principal Investigator, Mr. D. E. Pettit of the Fatigue and Fracture Mechanics Laboratory. He is assisted by Ms. K. N. Lauraitis in the area of Specimen Fabrication and Quality Control, Dr. J. T. Ryder in the Analysis and Methodology Development, Mr. W. Fitze in the area of Fractography, and Mr. W. E. Krupp in the area of Mechanical Testing.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

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LIST OF TABLES

SECTION 1

TECHNICAL BACKGROUND

The introduction of advanced composite materials into aircraft structural applications in recent years has necessitated the development of analytical methodologies to assure the same level of structural reliability found in comparable metal structures. Composite materials, however, are not well suited to a simple extrapolation of analysis methods used in metals. This is a result of the differences between the basic characteristics of composites and metals. For example, composites are strongly anisotropic by nature and contain major microscopic inhomogeneities consisting of the matrix/interface/fiber nature of the material.

Initial damage in composites may take many different forms which, unlike metals where most types of defect could conservatively be considered as cracks, may have entirely different initial characteristics and possibly propagate in a different manner. A common type of damage which is unique to composites is that due to low velocity impact. From an initial damage viewpoint, this type of damage is typical of that which can readily occur due to a tool being dropped or pieces bumping together. In service a similar damage can occur at higher velocities (but normally much lower impactor mass) due to hail or rocks flipped from tires, etc.

Associated with the difficulties in defining the exact nature of damage and its effect on service life is the added problem of developing adequate nondestructive inspection methods to detect the damage and analysis methods to define its severity. The development of methods of defining, detecting, evaluating, and analyzing these types of damage in a framework consistent with current durability and damage tolerance requirements is the problem area addressed in the current program. Specifically, the objectives of the current program are (1) to develop a statistically valid data base defining

the growth behavior of damage regions in graphite/epoxy composite material, (2) develop an analysis methodology that is capable of predicting (a) the growth of damage zones under fatigue loading and (b) the resulting residual strength of the structure with a given fatigue induced damage zone size and configuration, (3) determine the mechanisms of fatigue induced damage formation and propagation, and (4) define the threshold damage sizes which will not propagate and the associated damage zone formation criteria.

The current program is composed of three major phases: TASK I: Preliminary screening is designed to screen the static and fatigue induced damage growth characteristics of two damage types. Based on these results a single damage condition will be selected for study in Tasks II and III. TASK II: Damage Growth and Residual Strength Degradation Prediction develops statistically significant data sets of the static and fatigue life behavior and of the fatigue induced damage growth and residual strength behavior. Based on this data a model for predicting the damage growth characteristics and the subsequent residual strength will be developed. In TASK III: Effect of Fatigue Loading/Environment Perturbations, three variations in the loading/environmental parameters will be studied to evaluate the applicability of the model over a range of loading/environmental conditions and update the model if required.

SECTION 2

TASK I TEST PLAN DEVELOPMENT

During the preceding quarter the formalized draft of the TASK I Test Plan was prepared and submitted to the Air Force Project Engineer for review. Following discussion of the draft, the TASK I Test Plan was formally submitted for approval.[(1)] The following paragraphs present a brief overview of the final TASK I Test Plan.

The proposed Task I test matrix is presented in Table I. Item 1 tests (Table I) consist of standard quality control tension tests using duplicate specimens from each of the test panels fabricated. Item 2 tests consist of ten replicate tests in tension and ten replicate tests in compression for each of the four laminate/damage conditions. These tests will be conducted to failure without interruption. The ten replicates comprise what is considered the minimum set size required for a meaningful data set as discussed in Reference 2.

A subset of static compression tests are included in Item 3 to evaluate the inherent local buckling characteristics of the damaged laminate. This characteristic behavior is of importance since normal constrained compression testing may yield compressive failure values which are unrealistically high compared to the restraint conditions of a typical structure. These tests will thus supply additional specimen stability data to verify or give direction to the modification of the guides required in the subsequent R = -1 fatigue testing to assure that the specimen response simulates that of actual structure as closely as possible.

The tests shown in Table I as Item 4 tests are designed to provide the basic S-N curve for each of the four laminate/damage conditions while also providing the basic fatigue induced damage growth characteristics for each of the laminate/damage conditions. For these tests, three replicates will be tested

TABLE I. PROPOSED TASK I TEST MATRIX

Item	Test Type	Laminate/Damage Conditions	Replicates	Data Required	Total Number Of Test Specimens
1.	Panel Quality Control	2 laminates, no damage = 2	2 per panel x 5 panels per laminate	Quality control tensile data	20
2.	Initial Static Tension and Compression Strength Determinations.	2 laminates x 2 damage = 4	10 replicates x 4 conditions x 2 test types	Residual Strength	80
3.	Column Buckling Tests	2 laminates x 2 damage = 4	1 each x 4 column length x 4 conditions	Buckling conditions	16
4.	Base S-N Fatigue Tests	2 laminates x 2 damage = 4	3 replicas x 6 stress levels x 4 conditions	Base S-N data and damage propagation data	72
5.	Initial Static Compression Strength Determination	2 laminates x 2 damage = 4	2 replicas x 3 stress levels x 4 conditions	Damage growth and effect of TBE	24
6.	S-N Fatigue Tests	2 laminates x 2 damage = 4	3 replicas x 3 stress levels x 4 conditions	Damage growth and affect of TBE on damage growth	36
					248

at each of six stress levels to define the general R = -1 S-N characteristics for each of the four laminate/damage conditions. The damage growth will be monitored by use of a Holosonics Series 400 Holoscan unit, as described in Reference 3.

A subset of both static compression and fatigue tests are proposed to provide a statistically based answer as to the effect of TBE* on subsequent material behavior, as shown in Items 5 and 6 in Table I. No significant effect of TBE has been reported in static tension (Reference 4). Therefore a series of specimens will be tested in compression by loading duplicate specimens to each of three strain levels, removing them and running acoustic imaging analysis of the damage and then conducting TBE enhanced x-ray analysis. The specimens will then be reloaded to failure. In this manner a set of six specimen results per laminate/damage condition will be available for comparison with the 10 reference sets of data by nonparametric analysis. In addition, added data on damage growth under static loading will be available for subsequent analysis.

The subset of fatigue tests to examine the effect of TBE additions on the subsequent fatigue behavior will consist of running triplicate specimens at three of the six stress levels examined in Item 4 of Table I. These tests will be conducted using the same procedures as the Item 4 tests except that following each acoustic imaging examination, a TBE enhanced set of x-rays will also be taken. From these results both a direct comparison of the TBE enhanced x-ray and acoustic imaging inspection results will be obtained and a data base for examining the effect of the TBE on the fatigue behavior will be established.

The results of the Task I tests will thus provide (a) a data base for the selection of the stress riser (damage type) to be used in the Task II and III study, (b) the basic fatigue induced damage propagation characteristics of the damage zone over a range of stress levels, (c) the basic tension and

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* DIB (1, 4 diiodobutane) may be substituted with approval of the Technical Monitor.

compression static strength and static damage formation characteristics for the four laminate/damage conditions, and (d) data on the column buckling characteristics of the four laminate/damage conditions.

SECTION 3

TASK I SPECIMEN FABRICATION

During the preceding quarter, the major effort was directed at the qualification of the new material batch, panel fabrication and the preliminary impact damage study. Results of these activities are summarized in the following sections.

3.1 Material Qualification

The material to replace that lost in the freezer failure was received and has completed qualification testing. The Narmco Quality Control Test Results[5] are presented in Table II and the Lockheed Quality Control Test Results[6] are presented in Table III. Narmco Batch #1079 was found to meet all requirements and the material was accepted.

3.2 Panel Fabrication

Subsequent to material acceptance, panel fabrication was initiated as per the previously approved Quality Control Plan[7]. One preliminary impact study panel 20 x 24-inch has been fabricated for both the 32 and 24 ply layups. Five 36 x 46-inch panels each of the 32-ply quasi-isotropic laminate and the 24-ply 67% 0° laminate were then fabricated. A summary of the laminate panel numbers and the material code letter which has been assigned to each panel is shown in Table IV. All panels received a standard production ultrasonic C-scan inspection using a 1/4-inch diameter teflon disc standard, the results of which are summarized in Table IV. A typical C-scan is shown in Figure 1.

Following panel fabrication and inspection, a master panel layout was developed for each panel such as shown in Figure 2. A random sampling procedure was then used to select which coupons from each panel will have impact damage. Essentially the procedure is double random in that coupons for each test condition are randomly selected from each panel fabricated, and randomly assigned

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TABLE II. Summary of the Narmco Quality Control Tests for Rigidite 5208-T300 Certified Test Report No. 34776

TESTING RESULTS

ITEM # 1
MATERIAL: Rigidite 5208-T300 12"
Batch # 1079

Roll	Amount	Resin Content	Areal Fiber Weight	Mfg. Date	Test Date
10	24.2	41	144 grams/sq.meter	1-12-78	1-17-78
11	26.2	42	144		
12	25.7	41	144		
13	25.4	42	143		
14	25.6	40	144		
15	21.5	42	144		
16	21.5	41	144		
17	26.7	43	144		

Flow:	22%
Volatiles:	0.2%
Gel Time:	19.53 min. @ 350°F.
Tack:	Acceptable
Specific Gravity:	1.58/1.58/1.58: 1.58 g/cc avg.
Cured Fiber Volume:	66/66/66: 66% average
RT Long. Tensile Strength:	218,360/244,290/255,560: 239,400 psi avg.
RT Long. Tensile Modulus:	20.43/21.96/21.49: 21.29 x 10^6 psi avg
RT Long. Flex Strength:	282,390/292,310/271,330: 282,010 psi avg.
180°F. Long. Flex Strength:	273,050/298,270/247,490: 272,940 psi avg.
RT Long. Flex Modulus:	23.25/22.74/22.15: 22.71 x 10^6 psi avg.
180°F. Long. Flex Modulus:	24.30/23.16/21.95: 23.13 x 10^6 psi avg.
RT Short Beam Shear:	18,000/17,830/17,830: 17,890 psi avg.
180°F. Short Beam Shear:	15,040/14,840/15,670: 15,190 psi avg.
Cured Ply Thickness:	0.0047"

Discrepancy Sheets: Attached

TABLE III. SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR NARMCO RIGIDITE 5208-T300 MATERIAL BATCH #1079[6]

Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
	UNCURED PROPERTIES		
1. Areal Fiber Weight (4 req)	139 - 149 g/m^2	143 g/m^2	x
		144 "	x
		145 "	x
		144 "	x
		Ave. 144 "	
2. Infrared Spectrophotometric Anal. (1 req)	Conformance to file spectrogram	-	x
3. Volatiles (2 req) 60± 5 min at 350°F	2% Maximum	0.3% edge	x
		0.35% center	x
4. Dry resin content (4 req)(Sophlet)	38 - 44%	43.1% left	x
		43.4% left center	x
		43.1% right center	x
		44.0% right	x
5. Resin Flow at 350°F and 85 psi (2 req)	15 - 29%	19.0%	x
		18.9%	x
6. Gel Time at 350°F (2 req)	For information only	20.0 minutes	-
		20.3 minutes	-
7. Fiber Orientation	0°	-	x
	CURED LAMINATES		
1. Cured Fiber Volume, 16 ply panel (3 req)	60 - 68%	62.3	x
		65.0	x
		65.4	x
		Ave. 64.2	
2. Cured Fiber Volume, 8 ply panel (3 req)	60 - 68%	64.5	x
		64.5	x
		65.2	x
		Ave. 64.7	
3. Specific Gravity, 16 ply panel (3 req)	1.55 - 1.62	1.57	x
		1.57	x
		1.58	x
		Ave. 1.57	

TABLE III. SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR NARMCO RIGIDITE 5208-T300 MATERIAL BATCH #1079[6] (Continued)

Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
4. Specific Gravity, 8 ply panel (3 req)	1.55 - 1.62	1.57 1.57 1.58 Ave. 1.57	x x x
5. Tensile Strength, longitudinal at 75°F (3 req)	170 ksi min.	227 119 223 Ave. 216 ksi	x x x
6. Elastic Modulus, longitudinal at 75°F (3 req)	$20\cdot10^6$ psi min.	$20.6\cdot10^6$ $20.0\cdot10^6$ $21.0\cdot10^6$ Ave. $20.5\cdot10^6$	x x x
7. Flexural Strength at 75°F (3 req)	210 ksi min.	255 245 264 Ave. 254 ksi	x x x
8. Flexural Modulus at 75°F (3 req)	$18\cdot10^6$ psi min.	18.0 18.1 18.2 Ave. $18.1\cdot10^6$ psi	x x x
9. Flexural Strength at + 180°F (3 req)	200 ksi min.	224 238 231 Ave. 231 ksi	x x x
10. Flexural Modulus at + 180°F (3 req)	$16\cdot10^6$ psi min.	$18.4\cdot10^6$ $19.7\cdot10^6$ $20.0\cdot10^6$ Ave. $19.4\cdot10^6$ psi	x x x
11. Short Beam Shear Strength at 75° (3 req)	13 ksi min.	16.7 15.6 16.7 Ave. 16.3 ksi	x x x

TABLE III. SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR NARMCO RIGIDITE 5208-T300 MATERIAL BATCH #1079[6] (Continued)

Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
12. Short Beam Shear Strength at + 180°F (3 req)	12 ksi min	13.2	x
		13.6	x
		13.4	x
		Ave. 13.4 ksi	
13. Thickness per ply, 16 ply panel (5 req)	0.0046 - 0.0056 inch	0.0048	x
		0.0048	x
		0.0050	x
		0.0048	x
		0.0051	x
		Ave. 0.0049 inch	
14. Thickness per ply, 8 ply panel (5 req)	0.0046 - 0.0056 inch	0.0050	x
		0.0051	x
		0.0050	x
		0.0050	x
		0.0051	x
		Ave. 0.0050 inch	

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TABLE IV. SUMMARY OF PANEL IDENTIFICATION CODES

Laminate Type	Panel Number	Assigned Material Code	C-Scan Inspection Results
32-ply quasi-isotropic	2TY 1228	A	No indications
	1TY 1228	B	
	2TY 1227	C	
	1TY 1230	D	
	1TY 1229	E	No indications
24-ply 67% 0° Fibers	1TY 1238	H	No indications
	1TY 1236	J	
	2TY 1236	K	
	2TY 1234	L	
	1TY 1234	M	No indications

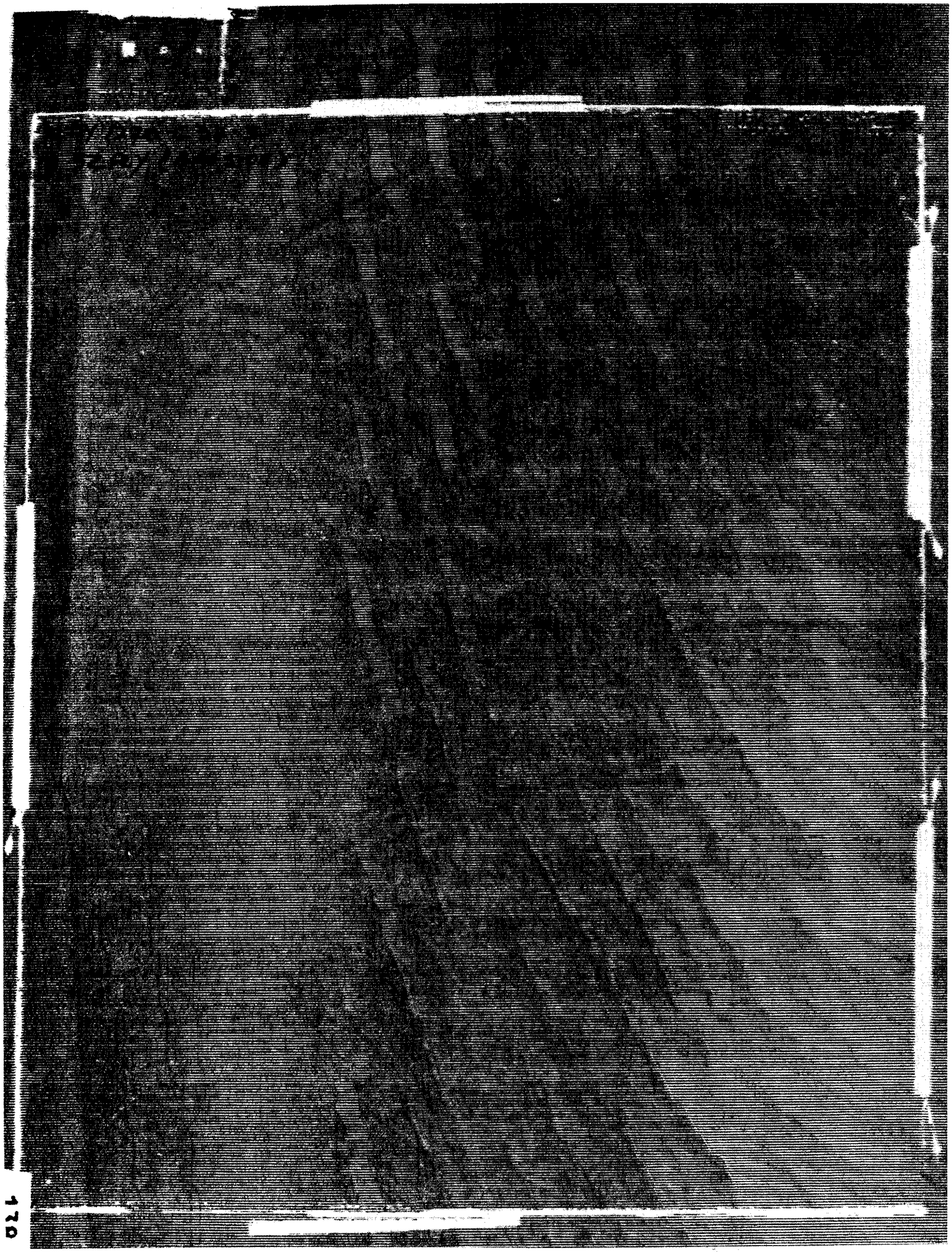

Figure 1. Typical Ultrasonic C-Scan Result for As Fabricated Panels

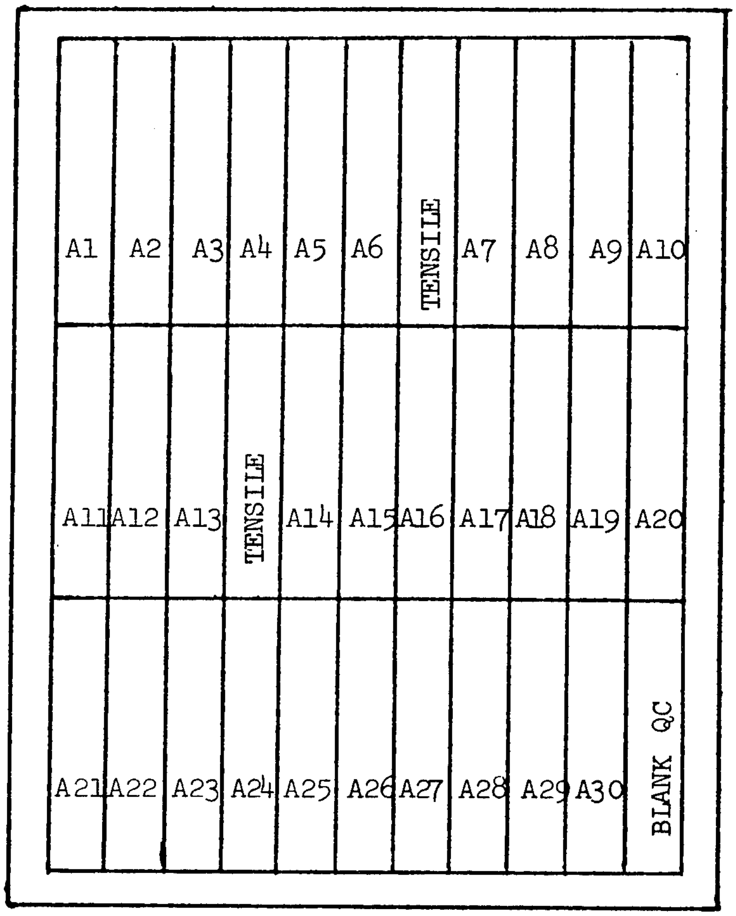

Figure 2. Typical Master Panel Layout as Prepared for Each Panel.

to a test condition and a test type. Randomization was accomplished using software programs developed at the Lockheed-California Company and based upon unbiased, Monte Carlo random number generators. A random number sequence was generated from 1 to 30 (the number of specimen blanks per panel) and a table of selection order vs. specimen number generated for each panel. The selection order 1 - 15 will be assigned to contain impact damage and sequence orders 16 - 30 assigned to contain a damaged hole. A typical result is illustrated in Table V. Next four random number tables were generated, one for each laminate and damage type to be studied. The panels of each laminate were then randomized by test as illustrated in Table VI. Randomization was conducted in sets of five (the number of panels per condition) to assure that all test panels are represented in a test type equally to eliminate any local statistically possible variations that would bias the sample in terms of a single panel. All panels are now ready for the introduction of the test damage conditions.

3.3 Preliminary Impact Damage Development Study

A key part of the specimen fabrication is the method of introducing the initial damage. Results at Lockheed (Reference 8) have shown narrow specimens, 1.8-inch wide, fail under low velocity impact in a manner which is not representative of the type of damage which occurs in 6-inch wide panels under the same conditions. The 1.8-inch wide specimens typically failed due to back ply failure across the entire specimen width. In contrast, a six-inch wide specimen exhibited internal delaminations. As a result, all impacting will be done on the 14.0 x 37-inch sub-panel rather than smaller specimen blanks.

A preliminary impact study panel 20 x 24-inches was fabricated in both layups with the Task I panels. These small panels were used to set the initial impact conditions to be used in developing the impact damage on the actual test specimens. For these tests, a simple drop tower consisting of a Teflon guide tube mounted in a support frame was used. The impactors used consisted of a one-inch diameter steel cylinder with interchangeable impact heads, one with a one-inch diameter hemispherical head and one with a No. 2 standard

TABLE V. RANDOMIZATION OF SPECIMEN SEQUENCES

Panel Number: 2TY 1227, Code C

Laminate: 32 ply

	Sequence Number	Specimen Number
Specimens to Contain Impact Damage	1	C-27
	2	C-11
	3	C-26
	4	C-28
	5	C-2
	6	C-7
	7	C-1
	8	C-18
	9	C-21
	10	C-15
	11	C-9
	12	C-16
	13	C-4
	14	C-10
	15	C-6
Specimens to Contain Damaged Holes	16	C-29
	17	C-19
	18	C-23
	19	C-20
	20	C-17
	21	C-12
	22	C-30
	23	C-14
	24	C-13
	25	C-5
	26	C-8
	27	C-24
	28	C-3
	29	C-25
	30	C-22

TABLE VI. ILLUSTRATION OF RANDOMIZATION OF PANELS BY TEST

Damage Type:	Impact		
Laminate:	32 Ply		
Panel Designations:	Code A (1)	Panel #:	________
	B (2)		________
	C (3)		________
	D (4)		________
	E (5)		________

Test Type	Number of Specimens Required	Panel	Corresponding Specimen No.
Static Tension	10	2	B-4 (First Spec. from Panel B)
		3	C-27 (First Spec. from Panel C)
		5	E-3 (First Spec. from Panel E)
		1	A-18 (First Spec. from Panel A)
		2	B-29 (Second Spec. from Panel B)
		1	A-6 (Second Spec. from Panel A)
		4	D-25 Etc.
		3	C-11
		5	E-10
		3	C-26
Static Compression	10	4	D-3
		5	
		2	
		etc.	etc.
Column Buckling	4	2	B-1
		etc.	etc.
Base S-N Tests	18	2	D-4
		etc.	etc.
TBE Static Compression	6	4	D-2
		etc.	etc.
TBE S-N Fatigue	9	1	A-6
Total Req.	57	etc.	etc.
Available Replacements	18	1	A-2
		4	D-29
		etc.	etc.

Phillips screwdriver point, and adjustable weight. Drop heights were preset by use of location pins which extend through the Teflon guide tube. Impactor velocity at impact, the deflection dynamics of the specimen and impactor, and the rebound velocity of the impactor were monitored by a high speed motion picture camera. Triplicate drops were made for each of four mass/heights with each of the two impactor head configurations at locations defined by a three-inch square grid on the panel. The test panels were supported during the impacting by a 3/8-inch thick section of HRH10-3/16-3.5 honeycomb core material. This support method was selected since tests have indicated(8) this provides a reproducible support system for low velocity impact testing. A typical drop test set-up is shown in Figure 3.

Following impacting, the study panels were ultrasonically C-scanned to determine the basic plan area view size of the resulting damage at each site. The results are shown in Figures 4 and 5 for the 32 and 24 ply laminates respectively. A summary of the impact conditions and approximate apparent width, X, and height, Y, of the individual damage sites is presented in Tables VII and VIII. Detailed examination of the impact damage is now underway using the Holoscan ultrasonic unit. Following the detailed evaluation, a single impact damage condition will be selected for study and specimen fabrication initiation.

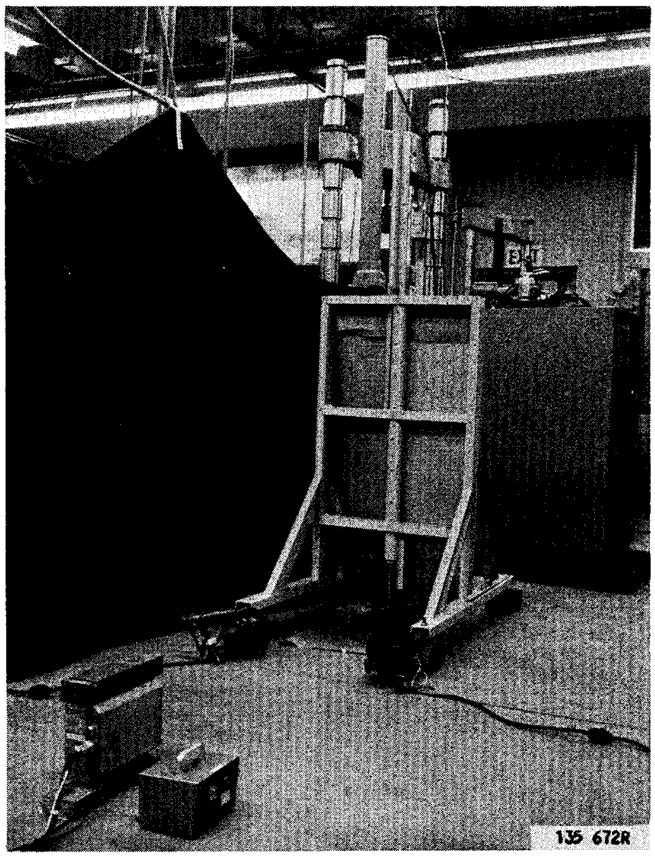

Figure 3. Typical Tool Drop Simulation Set Up

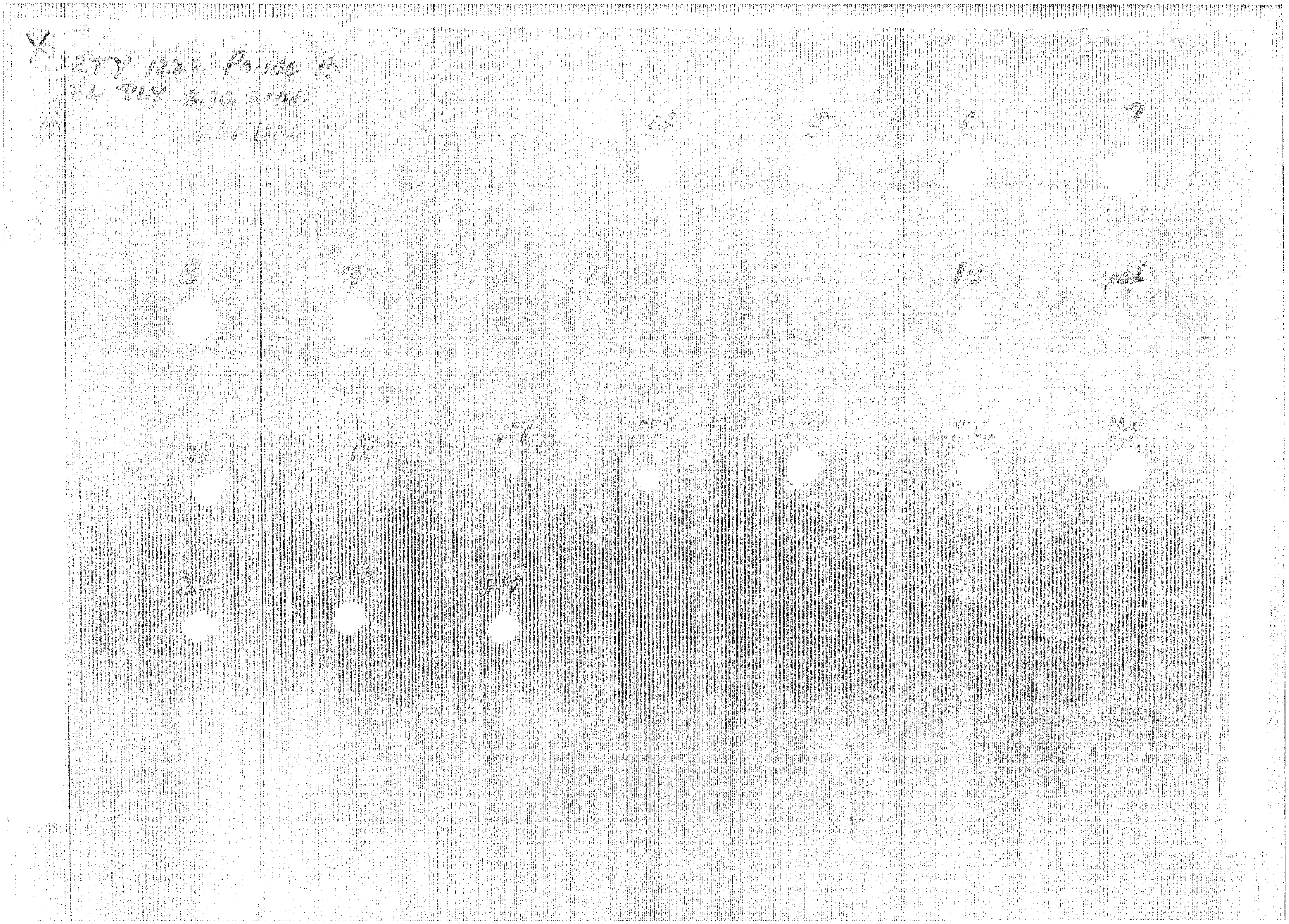

Figure 4. Ultrasonic C-Scan Results of the Preliminary Impact Damage Study on the 32-Ply Quasi-isotropic Laminate

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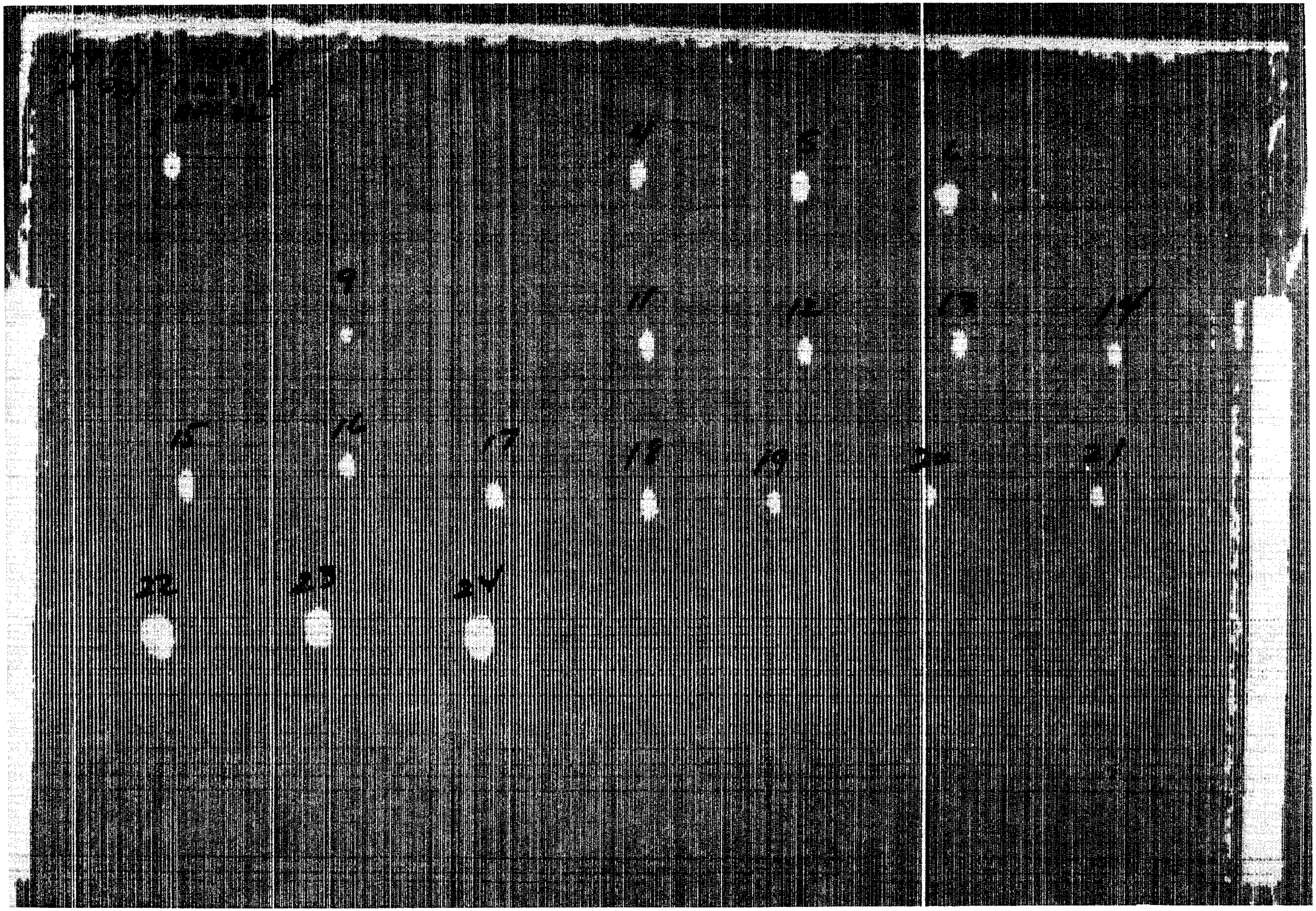

Figure 5. Ultrasonic C-Scan Results of the Preliminary Impact Damage Study on the 24 Ply 67% 0° Fiber Laminate.

TABLE VII. PRELIMINARY IMPACT DAMAGE EVALUATION RESULTS ON PANEL #2TY-1222, 32-PLY QUASI-ISOTROPIC

Location	Run Number	Drop Height, m	Drop Height, (inch)	Impact Head Type*	Impact Mass kg	Impact Mass (slug)	Impact Velocity m/sec	Impact Velocity (ft/sec)	Kinetic Energy E_K J	Kinetic Energy E_K (ft/lb)	Apparent Damage Size, x by y mm	Apparent Damage Size, x by y (inch)
1	37	1.24	(48.8)	1	0.240	(0.016)	4.02	(13.2)	1.94	(1.43)	0	0
2	38	1.24	(48.8)	1	0.240	(0.016)	3.96	(13.0)	1.87	(1.38)	0	0
3	39	1.24	(48.8)	1	0.240	(0.016)	4.11	(13.5)	2.02	(1.49)	0	0
4	40	0.48	(18.8)	1	0.590	(1.040)	2.44	(8.0)	1.75	(1.29)	17.8 x 19.0	(0.70 x 0.75)
5	41	0.48	(18.8)	1	0.590	(1.040)	2.50	(8.2)	1.84	(1.36)	17.5 x 17.3	(0.69 x 0.68)
6	42	0.48	(18.8)	1	0.590	(1.040)	-	-	-	-	18.3 x 18.3	(0.72 x 0.72)
7	43	0.73	(28.8)	1	0.590	(1.040)	3.29	(10.8)	3.20	(2.36)	20.8 x 23.1	(0.82 x 0.91)
8	44	0.73	(28.8)	1	0.590	(1.040)	3.23	(10.6)	3.08	(2.27)	21.6 x 22.4	(0.85 x 0.88)
9	45	0.73	(28.8)	1	0.590	(1.040)	3.35	(11.0)	3.31	(2.44)	20.3 x 22.6	(0.80 x 0.89)
10	46	0.73	(28.8)	1	0.240	(0.016)	3.23	(10.6)	1.25	(0.92)	0	0
11	47	0.73	(28.8)	1	0.240	(0.016)	3.47	(11.4)	1.44	(1.06	0	0
12	48	0.73	(28.8)	1	0.240	(0.016)	3.35	(11.0)	1.34	(0.99)	0	0
13	49	1.24	(48.8)	2	0.248	(0.017)	4.14	(13.6)	2.13	(1.57)	13.7 x 13.2	(0.54 x 0.52)
14	50	1.24	(48.8)	2	0.248	(0.017)	4.14	(13.6)	2.13	(1.57)	10.4 x 11.4	(0.41 x 0.45)
15	51	1.24	(48.8)	2	0.248	(0.017)	4.24	(13.9)	2.22	(1.64	12.4 x 12.7	(0.49 x 0.50)
16	52	0.73	(28.8)	2	0.248	(0.017)	3.17	(10.4)	1.25	(0.92)	2.5 x 1.2	(0.10 x 0.05)
17	53	0.73	(28.8)	2	0.248	(0.017)	3.35	(11.0)	1.40	(1.03)	3.0 x 5.3	(0.12 x 0.21)
18	54	0.73	(28.8)	2	0.248	(0.017)	3.26	(10.7)	1.32	(0.97)	10.2 x 8.9	(0.40 x 0.35)
19	55	0.73	(28.8)	2	0.598	(1.041)	3.23	(10.6)	3.01	(2.27)	16.5 x 16.5	(0.65 x 0.65)
20	56	0.73	(28.8)	2	0.598	(1.041)	-	-	-	-	17.3 x 16.8	(0.68 x 0.66)
21	57	0.73	(28.8)	2	0.598	(1.041)	3.54	(11.6)	3.69	(2.72)	19.8 x 20.0	(0.78 x 0.79)
22	58	0.48	(18.8)	2	0.598	(1.041)	2.96	(9.7)	2.58	(1.90)	14.7 x 14.5	(0.58 x 0.57)
23	59	0.48	(18.8)	2	0.598	(1.041)	2.59	(8.5)	1.98	(1.46)	15.2 x 15.2	(0.60 x 0.60)
24	60	0.48	(18.8)	2	0.598	(1.041)	2.47	(8.1)	1.80	(1.33)	14.0 x 14.7	(0.55 x 0.58)

* 1 = 1-inch diameter round head

2 = #2 Phillips Head Screwdriver point

TABLE VIII. PRELIMINARY IMPACT DAMAGE EVALUATION RESULTS ON PANEL #1TY-1222, 24-PLY 67% 0° FIBERS

Location	Run Number	Drop Height, m	(inch)	Impact Head Type*	Impact Mass kg	(slug)	Impact Velocity m/sec	(ft/sec)	Kinetic Energy E_K J	(ft/lb)	Apparent Damage Size, x by y mm	(inch)
1	31	0.477	(18.8)	1	0.240	(0.016)	2.65	(8.7)	0.84	(0.62)	8.9 x 10.7	(0.35 x 0.42)
2	32	0.477	(18.8)	1	0.240	(0.016)	2.65	(8.7)	0.84	(0.62)	0	0
3	33	0.477	(18.8)	1	0.240	(0.016)	2.74	(9.0)	0.89	(0.66)	0	0
4	34	0.732	(28.8)	1	0.164	(0.011)	3.26	(10.7)	0.87	(0.64)	8.1 x 13.2	(0.32 x 0.52)
5	35	0.732	(28.8)	1	0.164	(0.011)	3.32	(10.9)	0.91	(0.67)	10.2 x 14.2	(0.40 x 0.56)
6	36	0.732	(28.8)	1	0.164	(0.011)	3.26	(10.7)	0.87	(0.64)	10.7 x 15.2	(0.42 x 0.60)
7	61	0.477	(18.8)	1	0.164	(0.011)	2.68	(8.8)	0.59	(0.435)	0	0
8	62	0.477	(18.8)	1	0.164	(0.011)	2.53	(8.3)	0.53	(0.39)	0	0
9	63	0.477	(18.8)	1	0.164	(0.011)	2.56	(8.4)	0.54	(0.40)	5.6 x 6.4	(0.22 x 0.25)
10	64	0.477	(18.8)	1	0.240	(0.016)	2.53	(8.3)	0.77	(0.565)	0	0
11	65	0.477	(18.8)	1	0.240	(0.016)	2.50	(8.2)	0.75	(0.55)	7.6 x 14.2	(0.30 x 0.56)
12	66	0.477	(18.8)	1	0.240	(0.016)	2.53	(8.3)	0.77	(0.565)	7.9 x 12.2	(0.31 x 0.49)
13	67	0.477	(18.8)	2	0.248	(0.017)	2.65	(8.7)	0.87	(0.64)	7.4 x 12.2	(0.29 x 0.49)
14	68	0.477	(18.8)	2	0.248	(0.017)	2.59	(8.5)	0.83	(0.61)	7.4 x 10.2	(0.29 x 0.40)
15	69	0.477	(18.8)	2	0.248	(0.017)	2.65	(8.7)	0.87	(0.64)	7.1 x 13.0	(0.28 x 0.51)
16	70	0.732	(28.8)	2	0.172	(0.012)	3.17	(10.4)	0.87	(0.64)	7.6 x 10.2	(0.30 x 0.40)
17	71	0.732	(28.8)	2	0.172	(0.012)	3.23	(10.6)	0.89	(0.66)	7.9 x 11.4	(0.31 x 0.45)
18	72	0.732	(28.8)	2	0.172	(0.012)	3.29	(10.8)	0.94	(0.69)	7.1 x 14.7	(0.28 x 0.58)
19	73	0.477	(18.8)	2	0.172	(0.012)	2.53	(8.3)	0.56	(0.41)	6.6 x 10.2	(0.26 x 0.40)
20	74	0.477	(18.8)	2	0.172	(0.012)	2.65	(8.7)	0.60	(0.445)	5.8 x 10.2	(0.23 x 0.40)
21	75	0.477	(18.8)	2	0.172	(0.012)	2.59	(8.5)	0.58	(0.425)	5.3 x 9.6	(0.21 x 0.38)
22	76	0.477	(18.8)	1	0.590	(1.040)	2.53	(8.3)	1.88	(1.39)	15.7 x 21.3	(0.62 x 0.84)
23	77	0.477	(18.8)	1	0.590	(1.040)	2.53	(8.3)	1.88	(1.39)	13.0 x 18.5	(0.51 x 0.73)
24	78	0.477	(18.8)	1	0.590	(1.040)	2.65	(8.7)	2.07	(1.53	14.0 x 20.6	(0.55 x 0.81)

* 1 = 1-inch diameter round head

2 = #2 Phillips Head Screwdriver point

REFERENCES

1. Pettit, D. E., "Task I Test Plan for Residual Strength Degradation of Advanced Composite Materials," LR 28360-3, April 12, 1978.

2. Ryder, J. T., and Walker, E. K., "Ascertainment of the Effect of Compressive Loading on the Fatigue Lifetime of Graphite Epoxy Laminates for Structural Applications," AFML-TR-76-241, December 1976.

3. Pettit, D. E., "Residual Strength Degradation for Advanced Composites," Interim Technical Quarterly Report, LR 28360-2, Lockheed-California Company, Burbank, California, February 10, 1978.

4. Altman, J., Konicki, D., Burroughs, B., Nodler, M., "Advanced Composites Serviceability Quarterly Progress Report," Rockwell International Corp., NA-76-783-1, January 1977.

5. Certified Test Report No. 34255, Narmco Materials, Inc., Costa Mesa, California, January 17, 1978.

6. Quality Control Test Report for Laboratory Request No. 344984, Lockheed-California Company, Burbank, California, February 15, 1978.

7. Pettit, D. E., "Residual Strength Degradation for Advanced Composites," Interim Technical Quarterly Report, LR 28360-1, Lockheed-California Company, Burbank, California, November 11, 1977.

8. Pettit, D. E., "Experimental Techniques: Impact Damage of Composite Materials," Lockheed Report in progress, LR 28001, to be published.

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